JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY

Quality Changes and Nutrient Retention in Fresh-Cut versus Whole Fruits during Storage

MARÍA I. GIL,*,† ENCARNA AGUAYO,§ AND ADEL A. KADER#

Research Group on Quality, Safety and Bioactivity of Plant Foods, CEBAS-CSIC, P.O. Box 164, Espinardo, Murcia 30100, Spain; Postharvest and Refrigeration Group, Department of Food Engineering, Technical University of Cartagena, Po. Alfonso XIII 48, Cartagena, Murcia 30203, Spain; and Department of Plant Sciences, University of California, One Shields Avenue, Davis, California 95616

The influences of processing and storage on the quality indices and nutritional content of fresh-cut fruits were evaluated in comparison to whole fruits stored for the same duration but prepared on the day of sampling. Fresh-cut pineapples, mangoes, cantaloupes, watermelons, strawberries, and kiwifruits and whole fruits were stored for up to 9 days in air at 5 °C. The postcutting life based on visual appearance was shorter than 6 days for fresh-cut kiwifruit and shorter than 9 days for fresh-cut pineapple, cantaloupe, and strawberry. On the other hand, fresh-cut watermelon and mango pieces were still marketable after 9 days at 5 °C. Losses in vitamin C after 6 days at 5 °C were ≤5% in mango, strawberry, and watermelon pieces, 10% in pineapple pieces, 12% in kiwifruit slices, and 25% in cantaloupe cubes. No losses in carotenoids were found in kiwifruit slices and watermelon cubes, whereas losses in pineapples were the highest at 25% followed by 10−15% in cantaloupe, mango, and strawberry pieces after 6 days at 5 °C. No significant losses in total phenolics were found in any of the fresh-cut fruit products tested after 6 days at 5 °C. Light exposure promoted browning in pineapple pieces and decreased vitamin C content in kiwifruit slices. Total carotenoids contents decreased in cantaloupe cubes and kiwifruit slices, but increased in mango and watermelon cubes in response to light exposure during storage at 5 °C for up to 9 days. There was no effect of exposure to light on the content of phenolics. In general, fresh-cut fruits visually spoil before any significant nutrient loss occurs.

KEYWORDS: Carotenoids; color; firmness; minimal processing; phenolics; quality; storage; vitamin C

INTRODUCTION

There has been an increasing demand for fresh-cut fruits and vegetables, mainly because of their convenience as ready-to-eat products as well as for the health benefits associated with their consumption (*1*−*3*). A major benefit from a higher intake of fruits and vegetables may be the increased consumption of vitamins (vitamin C, vitamin A, vitamin B_6, thiamin, and niacin), minerals, and dietary fiber. Other constituents that may lower the risk of cancer and heart disease as well as prevent degenerative diseases include carotenoids, flavonoids, and other phenolics (*4*−*8*). Postharvest losses in nutritional quality, particularly vitamin C content, can be substantial and are enhanced by physical damage, extended storage duration, high temperatures, low relative humidity, and chilling injury of chilling-sensitive commodities (*9*−*13*).

Wounding of fruit tissues induces a number of physiological disorders that need to be minimized to obtain fresh-like quality products (*14*). Antioxidant constituents are susceptible to degradation when exposed to oxygen or light, to which the interior of the fruit is exposed by cutting (*15*−*17*). Oxidation also occurs on exposure to acidic pH or halides, such as hypochlorite used for sanitation (*18*). The interaction of these constituents with enzymes, such as ascorbate oxidase, polyphenol oxidase, cytochrome oxidase, and peroxidase, could also promote degradation. Browning due to oxidation of phenols, which is often catalyzed by the polyphenol oxidase enzyme to form colored melanins, decreases the nutrient content (*19*). Wounding also promotes the production of wound ethylene (*20*), which hastens senescence, including the oxidation of fatty acids by lipoxygenase, during which carotenoids may be degraded by co-oxidation (*21*).

Fresh-cut fruits are still under study because of the difficulties in preserving their fresh-like quality during prolonged periods (*14*). Interest on the part of consumers and producers has encouraged researchers to determine how fruit and vegetable antioxidant constituents can be maintained after processing (*18*, *22*−*24*). The main objective of the present work was to determine if fresh-cut fruits maintain their nutritional quality

* Author to whom correspondence should be addressed (telephone 34-968-396315; fax 34-968-396213; e-mail migil@cebas.csic.es).
† CEBAS-CSIC.
§ Technical University of Cartagena.
# University of California.

10.1021/jf060303y CCC: $33.50
Published on Web 05/12/2006

including vitamin C, carotenoids, and phenolics in comparison with the whole fruit when both are held for up to 9 days at 5 °C. Quality indices including visual quality, firmness, color, soluble solids content, titratable acidity, and pH were also evaluated.

MATERIALS AND METHODS

Plant Material. Pineapples (*Ananas comosus* L. cv. Tropical Gold) from Ecuador, mangoes (*Mangifera indiga* L. cv. Ataulfo) from Mexico, and kiwifruits (*Actinidia deliciosa* cv. Hayward) from New Zealand were obtained from a wholesale distribution center in Sacramento, CA. Cantaloupe (*Cucumis melo* L. cv. San Joaquin Gold) and watermelon (cv. Tri-X313) were harvested from fields in the San Joaquin Valley of California and transported to Davis, CA, within 1−2 h of harvest. Strawberries (*Fragaria* × *ananassa* cv. Seascape) from Watsonville, CA, were acquired on the day of harvest. All fruits used were obtained between July and August 2004 and transported from each location by air-conditioned vehicle to the Postharvest Laboratory at the University of California, Davis. Fruits were cooled to 5−7 °C before cutting. All fruits used were at acceptable ripeness stage based on eating quality, and no ethylene treatment was necessary to stimulate ripening, even for mangoes or kiwifruits. Fruits were sorted to remove damaged and poor-quality fruits and were further sorted by ground color and firmness. All fruits were grouped into two lots of 30 fruits each for pineapple, cantaloupo, and watermelon, 80 fruits each for kiwifruit and mangoes, and 20 kg each for strawberries. One lot was immediately processed as fresh-cut fruits, and the other lot was stored as whole fruits and was processed in the same way as the fresh-cut samples on the day of sampling.

Pineapple Pieces Preparation. The maturity stage was 3−4 according to the Dole pineapple color chart with a median weight ± standard deviation of 1921 ± 140 g. Pineapple peel and core were removed with a pineapple peeler (Fresh Cut Food Machinery, Boulder, CO). The peeled pineapples were sliced perpendicular to the blossom end−stem scar axis with a sharp stainless steel knife. From each fruit six or seven slices of 2 cm thick were made. Then, the fruit slices were cut into 2 × 2 × 2 cm pieces. Each sampling day, six to eight whole fruits were cut and processed as described for fresh-cut samples. Three replicates of 16 pieces each were used to represent stored whole fruit and compared with three stored replicates of fresh-cut pineapple.

Mango Cube Preparation. Fruits used had a firmness between 9 and 20 N with a median weight ± standard deviation of 283 ± 14 g. Mangoes were peeled with a sharp vegetable peeler, and the flesh was sliced from the seed into halves with a sharp nonserrated knife. Mango slices were cut into 2 × 2 × 2 cm cubes. Each sampling day, 20 fruits were cut and processed as described before. Three replicates of 20 cubes each were used to represent stored whole fruit and compared with three stored replicates of fresh-cut mangoes.

Cantaloupe Cube Preparation. Melons were harvested at commercial maturity. Two central rings were cut and the placenta tissue with the seeds and peel discarded. Melons were excised into trapezoid-shaped sections of 3 × 4 cm. Each sampling day, 8−10 whole stored fruits were cut and processed as described for fresh-cut samples. Three replicates of 12 pieces each were used to represent stored whole fruit and compared with three stored replicates of fresh-cut melon.

Watermelon Cube Preparation. Two central rings from each watermelon were cut into 4 cm cubes. Each sampling day, 8−10 whole stored fruits were cut and processed as described for fresh-cut samples. Three replicates of 10 pieces (4 × 4 cm each) were used to represent stored whole fruit and compared with three stored replicates of fresh-cut watermelon except for day 9, when cubes made from whole fruit stored at 14 °C, as the recommended temperature for whole watermelon (*25*), were also included.

Strawberry Slice Preparation. Fruits with less than three-fourths red surface color or over-ripe (dark red and soft) were eliminated. The stem was removed, and the fruits were cut perpendicular to the blossom end−stem scar axis with a sharp stainless steel knife. From each fruit were made four pieces. Each sampling day, 3 kg of fruits was cut and processed in the same way as strawberry slices. Three replicates of 150 g each were used to represent stored whole fruit and compared with three stored replicates of fresh-cut strawberries.

Kiwifruit Slice Preparation. Fruits used had a firmness of 4−6 N. Kiwifruits were peeled with a sharp vegetable peeler and sliced perpendicular to the blossom end−stem scar axis with a sharp nonserrated knife. From each kiwifruit were obtained five 7 mm thick slices. Each sampling day, 20 fruits were cut and processed as described before. Three replicates of 12 slices each were used to represent stored whole fruit and compared with three stored replicates of kiwifruit slices.

Washing and Storage. Cut fruits were placed in a colander and dipped in chlorinated (1.3 mM NaOCl) water at 5 °C for 2 min for sanitation. The proportion of chlorinated water/fruit weight was 3 kg of cut fruits/10 L of chlorinated water. Then, they were blotted dry with cheesecloth and randomly divided among 12 plastic clamshells (Nature Works, Minneapolis, MN) that were not gastight when closed. Three replicates of 10−20 pieces each (equivalent to 150−200 g) were used per storage duration (0, 3, 6, and 9 days at 5 °C).

Effect of Light Exposure. To study the effect of light exposure during storage, three replicates were exposed to the room's fluorescent light during 9 days while the rest were kept in darkness. The light intensity, measured by a LI-COR meter (LI-COR, Lincoln, NE), that reached the location of the fresh-cut fruits was 4−5 μmol m^{-2} s^{-1}.

Each sampling day, whole fruits stored at 5 °C were cut and processed in the same way as the fresh-cut fruit. In addition, whole watermelons that were stored at 14 °C were also included. All preparation steps were performed at 10 °C under sanitary conditions. After quality evaluation including firmness and color, the fruit pieces were frozen in liquid nitrogen and kept at −80 °C for a maximum of 2 weeks until analyzed. The frozen fruits were ground to a fine powder in liquid nitrogen before sampling to ensure uniformity. Frozen tissues were used for the extraction of phenolic compounds, vitamin C, and carotenoids.

Quality Evaluation. All quality evaluation procedures were performed at ≈20 °C. A panel of three judges (two women and one man) scored the visual quality. Ratings were based on a 9-point hedonic scale, where 9 = excellent, freshly cut; 7 = very good; 5 = good, limit of marketability; 3 = fair, limit of usability; and 1 = poor, unusable (*18*, *23*). Firmness of pieces was determined with a TA-XT Plus texture analyzer (Stable Micro System, Scarsdale, NY) as the force required for a 3-mm tip to penetrate to a depth of 5 mm in the center of the pieces of pineapple, mango, cantaloupe, and watermelon. The widest part of the shoulder of the cut surface in strawberry slices and the center of the green area in kiwifruit slices were penetrated to a depth of 5 mm.

Color Measurement. Objective color measurements were assessed using a Minolta Chroma Meter CIE 1976 (model CR-200, Minolta Corp., Ramsey, NJ) calibrated with a white plate. CIE refers to the Commission Internationale de l'Eclairage (International Commission on Illumination) (*26*). Color was expressed as CIELAB ($L^*a^*b^*$) color space, where L^* defines the lightness and a^* and b^* define the red-greenness and blue-yellowness, respectively. Hue angle ($H°$) was calculated as H = arctangent b^*/a^* (*27*). The more representative color parameters are included in the results. Color was evaluated in the same area in which the firmness measurements were made. In both cases, 10 pieces per replicate were used.

Determination of Titratable Acidity, pH, and Soluble Solids. Juice samples were obtained by squeezing half of the fruit slices from each replicate through four layers of cheesecloth with a hand juicer. Soluble solids content (SSC) of the juice was measured with an Abbé Refractometer, model 10450 (American Optical, Buffalo, NY), and expressed as a percentage. An automatic titrator (Radiometer, Copenhagen, Denmark) equipped with a PHM85 Precision pH-meter, ABU80 Autoburet, PRS12 Alpha printer, and a SAC80 sample changer was used to measure pH and titratable acidity (TA). A 4-g juice sample per replicate was diluted with 20 mL of distilled water and titrated with 0.1 N NaOH to pH 8.1. TA was calculated as percent of anhydrous citric acid as the predominant acid.

Extraction of Phenolic Compounds. The extraction procedure was based on that of Tomás-Barberán et al. (*28*) except for strawberries, for which the protocol of Gil et al. (*29*) was used. Ten grams of frozen fruit was homogenized with 10 mL of water/methanol (2:8) containing

Table 1. Quality Indices of Whole and Fresh-Cut 'Gold' Pineapple Stored for up to 9 Days at 5 °C[a]

days	pineapple	visual quality (1–9)	firmness (N)	color (*b** value)	soluble solids (%)	titratable acidity (%)	pH
initial		8.8	3.91	38.35	12.2	0.64	3.53
3	whole	9.0 a	3.85 a	38.97 a	11.6 b	0.76 a	3.52 b
	fresh-cut	7.0 b	3.82 a	32.88 b	13.0 a	0.66 a	3.54 a
6	whole	7.0 a	3.92 a	40.45 a	11.1 b	0.74 a	3.51 a
	fresh-cut	5.0 b	3.67 a	31.21 b	12.2 a	0.64 a	3.59 a
9	whole	7.0 a	3.62 a	38.90 a	11.9 b	0.60 b	3.57 b
	fresh-cut	4.0 b	3.78 a	29.81 b	11.9 b	0.66 a	3.56 b
	fresh-cut (light)	3.0 c	3.64 a	29.12 b	12.9 a	0.66 a	3.64 a

[a] Means ($n = 3$) in each column followed by the same letter at each time do not differ significantly at $P < 0.05$.

4 mM NaF for 1 min on ice. Homogenates were centrifuged at 10500*g* in an Eppendorf centrifuge (model Sigma 1-13, Braun Biotech International, Osterode, Germany) for 5 min at 2−5 °C. The supernatant was recovered, filtered through 0.45-μm filters, and directly analyzed by HPLC. Samples of 50 μL of extracts were analyzed using an HPLC system (Hewlett-Packard 1050 pump) coupled with a photodiode array detector (DAD) (series 1040M, series II) and an autosampler (series 1050), operated by HP ChemStation software. A reversed phase C_{18} Nucleosil column (150 × 4.6 mm; particle size = 5 μm) with a guard column containing the same stationary phase (Safeguard holder 5001-CS) was used. Water (A) and methanol (B) containing formic acid (95:5 v/v) were used as the mobile phases. The linear gradient started with 10% B in A to reach 35% B in A at 40 min and 80% B at 60 min to follow isocratically for 5 min to reach the initial conditions after 10 min. The flow rate was 1 mL min^{-1}, and chromatograms were recorded at 280 and 340 nm. The phenolic compounds analysis for strawberry was carried out as described by Gil et al. (*30*).

Phenolic compounds were characterized by their UV spectra, recorded with a diode array detector and HPLC-MS-MS ESI (Hewlett-Packard 5989A quadrupole instrument equipped with an electrospray interface HP 59987A), and, whenever possible, by chromatographic comparisons with authentic markers. Column and chromatographic conditions for HPLC-MS-MS analyses were the same as those used for HPLC-DAD analyses. Individual phenolic acids were quantified by comparison with external standards of phenolic acids as caffeic acid, *p*-coumaric acid, *p*-hydroxybenzoic acid, and gallic acid (Sigma, St. Louis, MO), flavonols as quercetin 3-*O*-glucoside (Merck, Darmstadt, Germany), and anthocyanins as pelargonidin (Apin Chemicals Ltd., Abingdon, U.K.). The results were expressed as milligrams per 100 grams of fresh weight (FW). Repeatability of the analyses was ±5%.

Extraction and Analysis of Vitamin C. Procedures used were as described by Wright and Kader (*18*) based on the method of Zapata and Dufour (*30*) with some modifications. Ten grams of frozen fruit was added to 10 mL of extraction medium (0.1 M citric acid, 0.05% w/v EDTA disodium salt, 5% v/v methanol, and 4 mM NaF). The mixture was directly homogenized for 30 s on ice and filtered through cheesecloth. The filtrate was collected and centrifuged at 10500*g* in an Eppendorf centrifuge for 5 min at 2−5 °C. The pH of the filtrate was adjusted to 2.35−2.40 and flushed through an activated Sep-Pak C_{18} cartridge (Waters, Milford, MA) and then filtered through a 0.45-μm filter. Then, 1 mL of 1,2-phenylenediamine dihydrochloride (OPDA) solution (35 mg/100 mL) was added to 3 mL of extract for dehydroascorbic acid derivatization into the fluorophore 3-(1,2-dihydroxyethyl)furo[3,4-*b*]quinoxaline-1-one (DFQ). After 37 min in darkness, samples were analyzed by HPLC. The HPLC system was the one described for phenolics. The content of vitamin C (Vit C) was calculated by adding ascorbic acid (AA) and dehydroascorbic acid (DHA) contents, and results are expressed as milligrams per 100 grams of FW. Standards of L-ascorbate, supplied by Sigma Chemical Co., and dehydroascorbate, from Aldrich Chemical Co., were used.

Extraction and Analysis of Carotenoids. Procedures used were as described by Wright and Kader (*22*) based on the method of Hart and Scott (*31*) for the determination of carotenoids by HPLC. Five grams of sample was added to 5 mL of methanol plus 10 mL of hexane containing 0.1% BHT. The sample was homogenized with a Polytron homogenizer at medium speed for 1 min. The mixture was then centrifuged for 10 min at 7000*g*. The carotenoid hexane layers were transferred and dried down under nitrogen. An additional 5 mL of hexane was added, and the mixture was homogenized at low speed for 30 s and then centrifuged as before. The extraction step was repeated until no remaining yellow color of the aqueous layer was observed. The combined hexane extracts were evaporated under nitrogen just to dryness, redissolved in acetonitrile, and then filtered through a 0.45-μm filter into an amber sample vial and immediately analyzed by HPLC. All the extraction steps were carried out under dimmed lights, and the tubes were wrapped in aluminum foil to exclude light. A Hewlett-Packard 1050 liquid chromatograph, coupled with a photodiode array detector (DAD) and a C18 300A Phenomenex (250 × 4.60 mm Jupiter 5 μm) was used. The mobile phase consisted of acetonitrile, methanol, and methylene chloride, 75:20:5 v/v/v, containing 0.1% butylated hydroxytoluene and 0.05% triethylamine. The methanol contained 0.05 M ammonium acetate. The flow rate was 1.5 mL/min. Detection was at 450 nm. Identification was confirmed by comparing the UV−vis spectra with those of reference compounds and by injection and co-injection of reference compounds. Quantitation was carried out by external standardization with calibrated solutions of standards: β-carotene, α-carotene, lycopene, and lutein were purchased from Sigma Chemical Co., and β-cryptoxanthin was acquired from Indofine (Chemical Company, Inc., Hillsborough, NJ). Total carotenoids contents were calculated as the sum of carotenoids peak areas expressed as micrograms per 100 grams of FW.

Statistical Analysis. There were three repetitions per evaluation period for whole and fresh-cut fruits. Analysis of variance (ANOVA) was performed for the quality indices. Means were separated at the 5% significance level by the least significant difference test (LSD). SigmaStat 2.0 statistical software was used.

RESULTS AND DISCUSSION

Pineapple. *Changes in Quality Indices.* As expected, pineapple pieces obtained from the whole stored fruit showed a better visual quality than the fresh-cut pieces at each evaluation day (**Table 1**). At day 9, fresh-cut pineapple was judged to be under the limit of marketability, and therefore the shelf life was shorter than 9 days in air. However, the end of postcutting life in pineapple was 12 days at 5 °C under the most favorable controlled atmosphere conditions (2 kPa of O_2 + 10 kPa of CO_2) or even up to 14 days at 10 °C with antibrowning agents (*32*, *33*). Pineapple firmness was well maintained after cutting because there was no significant difference between fresh-cut pieces and pieces from the stored whole fruit. Color (*b** value) of pieces from the whole pineapple was better preserved, whereas it decreased in fresh-cut pineapple, indicating a paler color. Changes in SSC, TA, and pH between fresh-cut pieces and pieces from whole pineapple were more related to sample variability than to the effect of processing and storage. At the end of storage, there was no difference in SSC and pH between

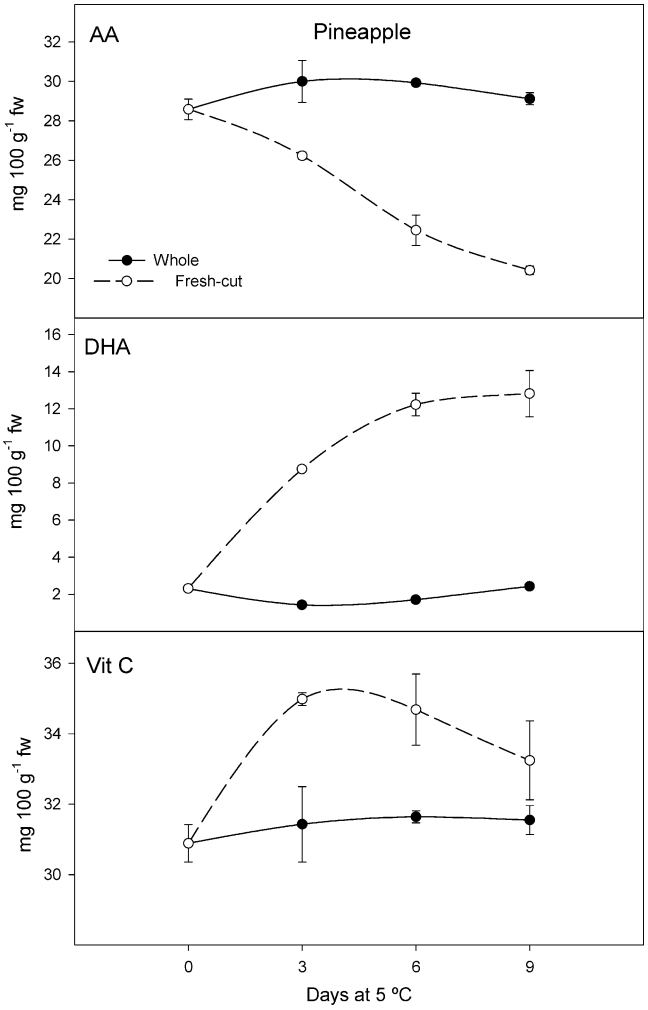

Figure 1. Ascorbic acid (AA), dehydroascorbic acid (DHA), and vitamin C (Vit C) of pineapple pieces from whole stored or fresh-cut fruit. Values are means of three replicates of 16 pieces each ± standard error.

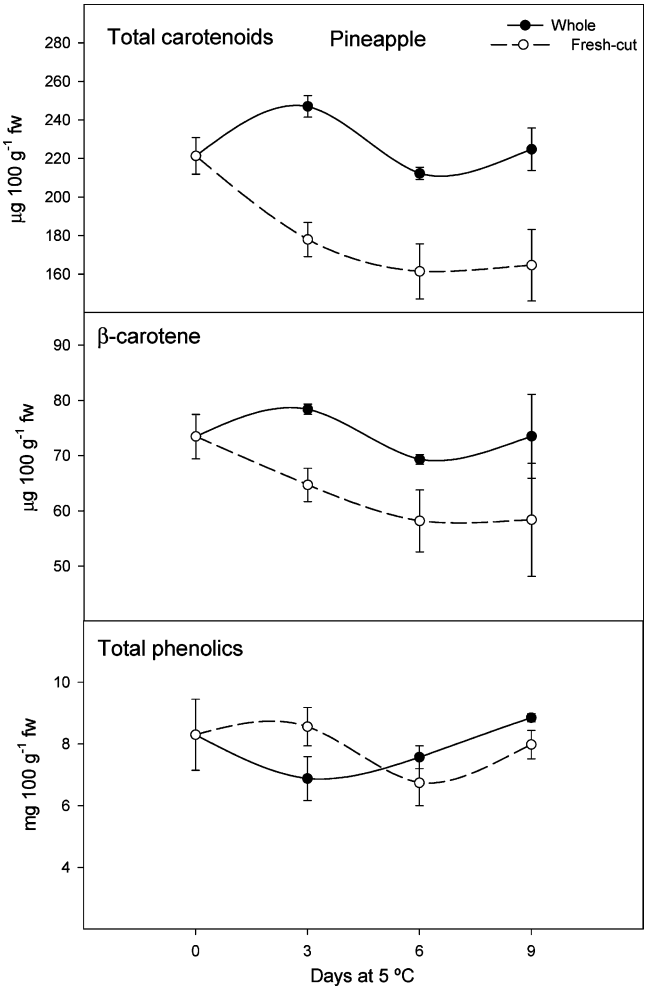

Figure 2. Total carotenoids, β-carotene and total phenolics content of pineapple pieces from whole stored or fresh-cut fruit. Values are means of three replicates of 16 pieces each ± standard error.

whole and fresh-cut pineapple. The TA of whole pineapple did not change until day 6. It was 0.76 and 0.74 at days 3 and 6, and at day 9 it decreased to 0.60. The decrease in TA or increase in pH was related to deterioration of fruit characteristics such as firmness and visual quality. When pineapple pieces were exposed to light, a decrease in visual quality was observed mainly related to surface browning, whereas dark storage conditions provided a better visual quality (**Table 1**).

Changes in Vitamin C. Pieces from whole stored fruit maintained AA and DHA during 9 days at 5 °C. However, there was a significant loss of AA but an increase in DHA throughout the storage for fresh-cut pineapple, resulting in greater vitamin C content of fresh-cut versus whole fruit (**Figure 1**). Under stress conditions, such as cutting or light exposure, ascorbate oxidase has been described to promote the transformation of AA to DHA (*18*). The concentration of AA often decreases during storage and processing of fruit and vegetables (*34*), and browning has been related to this degradation (*35*). However, because AA can be easily converted into DHA, it was essential, as in this case, to measure both AA and DHA to observe that the content of vitamin C was well preserved in fresh-cut pineapple.

Changes in Carotenoids. The cultivar used was a golden yellow flesh with high carotenoids content (250 μg 100 g^{-1} of FW) compared to other yellowish flesh cultivars with lower content (100 μg 100 g^{-1} of FW). The carotenoids extract of pineapple showed 14 peaks exhibiting typical carotenoids spectra. The total carotenoids content of 'Tropical Gold' pineapple flesh agrees with that reported for other golden cultivars, although a new hybrid was described to contain 2−2.5 times more carotenoids than the gold cultivars (*36*). During storage at 5 °C, the total carotenoids content of cubes from the whole pineapple was stable during storage, and no significant changes were observed after 9 days. However, after 3 days, there was a decrease in total carotenoids of fresh-cut samples resulting in a 25% reduction relative to the whole fruit. Changes in total carotenoids and β-carotene contents were similar (**Figure 2**).

Changes in Phenolics. Pineapple contained a small amount of phenolics (8 mg 100 g^{-1} of FW). The main phenolics identified coincided with those reported by Wen et al. (*37*): glucosylcoumaric acid, glucosylferulic acid, glucosylsinapic acid, caffeoylquinic acid, *p*-coumaroylquinic, *S*-sinapylgluthathione, *N*-glutamyl-*S*-sinapylcysteine, and another unidentified sinapyl derivative. In addition, dimethylfuranone-α-D-glucoside and dimethylfuranone were also identified. The different compounds were characterized by HPLC-MS-MS (data not shown). After slicing, the total phenolics contents in both whole and fresh-cut pineapple were quite stable, and no significant differences were found in the phenolics content of whole and fresh-cut pineapple after 9 days of storage at 5 °C (**Figure 2**).

No differences in the content of vitamin C, total carotenoids, and total phenolics were found between fresh-cut pineapple pieces kept under light or dark conditions (**Table 2**).

Table 2. Effect of Light Exposure on Vitamin C, Total Carotenoids, and Total Phenolics of Fresh-Cut Pineapple, Mango, Cantaloupe, Watermelon, Strawberry, and Kiwifruit Stored for 9 Days at 5 °C[a]

	vitamin C (mg 100 g^{-1} of FW)		total carotenoids (μg 100 g^{-1} of FW)		total phenolics (mg 100 g^{-1} of FW)	
fresh-cut fruit	dark	light	dark	light	dark	light
pineapple	33.2 ± 1.1	32.4 ± 0.2	164.7 ± 18.5	165.9 ± 15.1	8.0 ± 0.5	8.0 ± 1.0
mango	71.6 ± 0.5	72.5 ± 2.5	2272.1 ± 164.6	2789.6 ± 125.6	9.0 ± 0.3	9.5 ± 0.2
cantaloupe	15.6 ± 1.1	15.6 ± 0.3	3156.8 ± 628.6	2144.9 ± 468.8	4.4 ± 0.0	4.8 ± 0.3
watermelon	3.1 ± 0.2	3.7 ± 0.2	6919.2 ± 213.9	7780.4 ± 346.6	3.3 ± 0.3	3.5 ± 0.3
strawberry	31.5 ± 0.8	29.8 ± 0.4	83.9 ± 4.0	98.5 ± 11.5	46.9 ± 1.8	48.5 ± 2.8
kiwifruit	40.0 ± 1.0	35.5 ± 2.7	280.2 ± 10.1	232.7 ± 12.8	3.6 ± 0.2	3.8 ± 0.1

[a] Means ($n = 3$) ± standard error. FW, fresh weight.

Table 3. Quality Indices of Whole and Fresh-Cut 'Ataulfo' Mango Stored for up to 9 Days at 5 °C[a]

days	mango	visual quality (1–9)	firmness (N)	color (b^* value)	soluble solids (%)	titratable acidity (%)	pH
initial		9.0	1.36	64.02	13.7	1.25 a	3.27
3	whole	8.5 a	1.59 a	62.54 a	13.4 a	1.31 a	3.32 a
	fresh-cut	7.8 a	1.75 a	62.37 a	13.1 b	1.26 a	3.27 a
6	whole	8.8 a	1.55 a	63.72 a	14.3 a	1.36 a	3.31 a
	fresh-cut	7.5 b	1.76 a	61.05 b	13.6 b	1.28 a	3.27 a
9	whole	7.3 a	1.55 a	65.02 a	14.4 a	1.38 a	3.32 a
	fresh-cut	5.8 b	1.73 a	60.55 b	14.0 b	1.23 b	3.30 a
	fresh-cut (light)	6.0 b	1.73 a	60.60 b	14.1 ab	1.21 b	3.34 a

[a] Means ($n = 3$) in each column followed by the same letter at each time do not differ significantly at $P < 0.05$.

Mango. *Changes in Quality Indices.* Fresh-cut mango cubes maintained good visual quality up to day 9 of storage at 5 °C. After 6 days of storage, slight differences in visual quality between fresh-cut and whole fruit were observed (**Table 3**). The end of shelf life was reported to be 8 days at 5 °C for 'Kent' mango cubes (*38*). Slight browning on the skin surface was observed on those cubes with some remaining peel, and therefore complete skin removal must be recommended to avoid brown discoloration. Mango cubes were firm during the entire storage period, and no significant differences were observed between fresh-cut and whole fruit. The effect of processing and storage resulted in a decrease in color b^* value after 6 days of storage. There were no significant changes in SSC, TA, and pH during the storage of mangoes. In addition, no significant differences in quality indices were shown between mango cubes exposed to light or dark conditions after 9 days of storage (**Table 3**).

Changes in Vitamin C. Whole mangos maintained the vitamin C content after 9 days, and there were no differences in AA and DHA content during storage, except at day 9 when a high content in AA and vitamin C was observed, probably due to the variation in fruit maturity as shown by the initial firmness (**Figure 3**). A similar behavior was observed for those fresh-cut mango cubes with a decrease in AA and an increase in DHA during storage, maintaining the content of vitamin C close to the initial and to both fresh-cut and whole fruit, except at day 9 when the high AA and vitamin C contents of whole fruit were rather different. The USDA Nutrient Database (*39*) has reported lower amounts for vitamin C in other mango cultivars (30 mg 100 g^{-1} of FW) than what we found in 'Ataulfo' mango (80 mg 100 g^{-1} of FW). The effect of slicing and processing resulted in a decrease in the content of vitamin C by 8.3 mg 100 g^{-1} of FW (≈10%) compared with the initial (**Figure 3**). No differences in vitamin C were observed between mango cubes stored in the dark or under light exposure (**Table 2**). Fresh-cut mango dipping in vitamin C has been used to prevent cut surface browning and to enhance the vitamin C content (*24*).

Changes in Carotenoids. Total carotenoids content of different mango cultivars has been reported to be in the range of 900−9200 μg 100 g^{-1} of FW (*40*). 'Ataulfo' mangoes showed an average amount of 3000 μg of carotenoids 100 g^{-1} of FW. The major carotenoid of this cultivar was β-carotene, making up 40% of the total content, whereas α-carotene was present in only small amounts. The total carotenoids content of whole mangoes was quite stable during storage, and no significant changes were observed when compared with the initial contents (**Figure 4**). Fresh-cut mango cubes had a slightly lower total carotenoids content than those cubes obtained from the whole stored fruit, this difference being especially remarkable at the end of storage. The effect of slicing and storage was shown only after 9 days of storage when a reduction of 25% on the total carotenoids content of fresh-cut mango with respect to the initial values was observed. Mango cubes exposed to light showed a higher total carotenoids content than the ones held in the dark (**Table 2**).

Changes in Phenolics. Mango contained a small phenolics content of ≈10 mg 100 g^{-1} of FW. The main phenolic compounds detected in mango were a gallic acid dimer (*m*-digallic acid) (*41*) (quantified as gallic acid) and *p*-coumaroylglucose, feruloylglucose, and a small amount of chlorogenic acid (quantified as caffeic acid). These compounds were tentatively identified by HPLC-MS-MS. Fresh-cut mango cubes and cubes from the whole fruit showed a slight decrease in the total phenolics content after 3 days, but it was maintained thereafter (**Figure 4**). However, the decrease was only by 2 mg 100 g^{-1} of FW. The total polyphenol content in mango cubes was slightly increased by the presence of light (**Table 2**).

Cantaloupe. *Changes in Quality Indices.* The visual quality of fresh-cut cantaloupe decreased over storage time, and for each day they were judged with lower scores, whereas those cantaloupe cubes processed from the whole stored fruit had better visual quality (**Table 4**). Fresh-cut cantaloupe was under the limit of marketability by day 9 as in previous studies (*42*). Cube firmness decreased over the 9-day storage period as

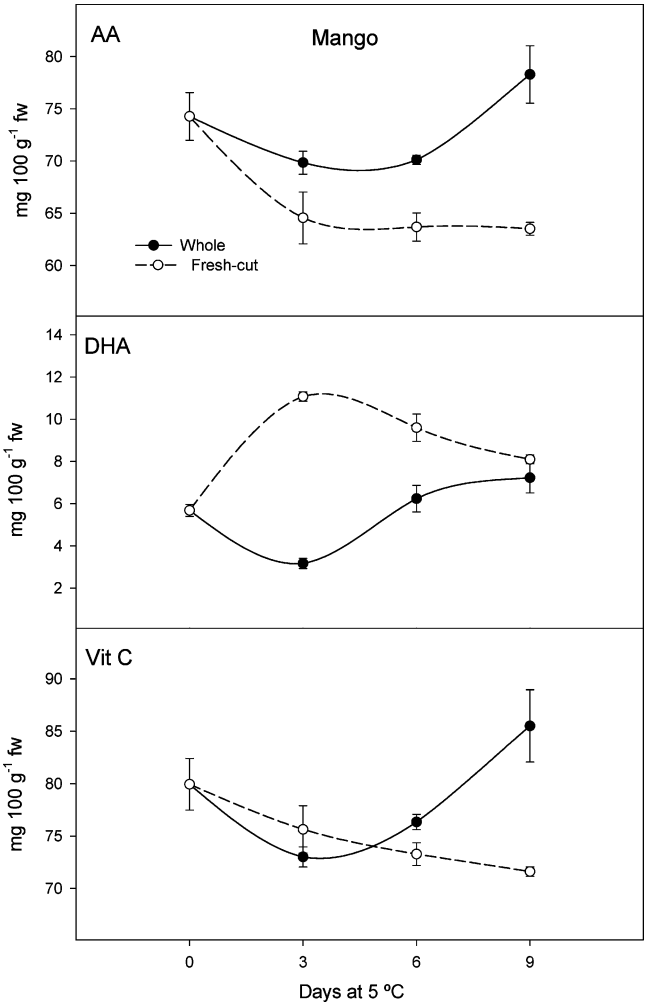

Figure 3. Ascorbic acid (AA), dehydroascorbic acid (DHA), and vitamin C (Vit C) of mango cubes from whole stored or fresh-cut fruit. Values are means of three replicates of 20 cubes each ± standard error.

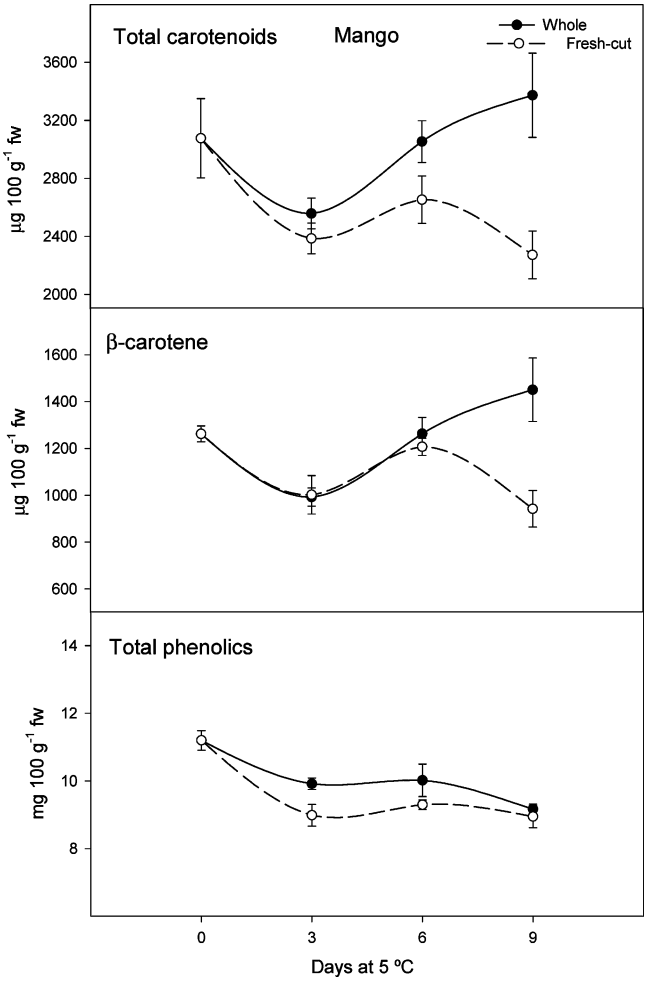

Figure 4. Total carotenoids, β-carotene, and total phenolics content of mango cubes from whole stored or fresh-cut fruit. Values are means of three replicates of 20 cubes each ± standard error.

reported by other authors (*43*), with no differences after 6 days between fresh-cut and whole cantaloupe. After storage, firmness was reduced by 36 and 41% in cubes from the whole and fresh-cut cantaloupe, respectively. During storage, color *b** values of whole cantaloupe did not change, whereas fresh-cut values decreased. There were no differences in SSC, TA, and pH among cubes from whole or fresh-cut cantaloupe up to day 6. However, a slight increase in TA and a decrease in pH were observed in fresh-cut cubes when the limit of marketability was exceeded (**Table 4**). In addition, there were no differences in the quality indices of cantaloupe cubes exposed to light and those in the dark except the pH was lower for light-exposed cubes (**Table 2**).

Changes in Vitamin C. The initial vitamin C content in cantaloupe melon was 20 mg 100 g^{-1} of FW including AA and DHA in the same proportion. During storage of fresh-cut cantaloupe, the AA content was well preserved, whereas DHA decreased after 3 days (**Figure 5**). Vitamin C in whole cantaloupes was better preserved than in fresh-cut cubes during storage, although differences were minimal (<5 mg 100 g^{-1} of FW). Lamikanra and Watson (*44*) demonstrated that cantaloupe melon peroxidase activity could be related to the tissue's response to increased oxidative stress in the cut fruit and promoted DHA degradation because it is less stable than AA (*15*).

Changes in Carotenoids. β-Carotene was found to be 85% of the total carotenoids. The content of total carotenoids in 'San Joaquin Gold' cantaloupes was ≈2−2.5 times higher than those found in other cantaloupe cultivars (*45*). The total carotenoids content in both fresh-cut and whole cantaloupe cubes decreased after cutting, but it was followed by a steady content over the time of storage (**Figure 6**). Changes in the content of carotenoids during storage were not significantly different, and the concentration of β-carotene was well maintained during this period.

Changes in Phenolics. Cantaloupes contained small amounts of phenolics (≈6 mg 100 g^{-1} of FW) that were not identified but quantified as gallic acid. There was no significant difference in the concentration of total phenolics of whole and fresh-cut cantaloupe over the storage, although there was a slight decrease in the fresh cut melon after 9 days of storage (**Figure 6**).

No effect of light exposure for 9 days of storage was observed for vitamin C and total phenolics between cantaloupe cubes exposed to light or dark conditions. However, a decrease in total carotenoids content was observed in those cubes exposed to light conditions (**Table 2**).

Watermelon. *Changes in Quality Indices.* Whole watermelons were stored at both 5 and 14 °C, and each sampling day after processing, their cubes were compared with those of fresh-cut fruits. The visual quality of fresh-cut watermelons decreased over storage, but they were still marketable at the end of the study (**Table 5**). Storage of whole watermelon at 14 °C resulted in the maintenance of good visual quality for up to 9 days, whereas the visual quality of the watermelon stored at 5 °C decreased over storage. These results clearly showed that

Table 4. Quality Indices of Whole and Fresh-Cut 'San Joaquin Gold' Cantaloupe Stored for up to 9 Days at 5 °C[a]

days	cantaloupe	visual quality (1–9)	firmness (N)	color (*b** value)	soluble solids (%)	titratable acidity (%)	pH
initial		8.8	2.57	36.52	9.6	0.04	6.79
3	whole	7.5 a	2.29 a	37.37 a	9.8 a	0.05 a	6.82 a
	fresh-cut	6.0 b	2.01 b	35.82 b	9.5 b	0.04 a	6.83 a
6	whole	7.5 a	1.89 a	36.94 a	9.8 a	0.05 a	6.64 a
	fresh-cut	5.0 b	2.02 a	33.47 b	9.4 a	0.05 a	6.65 a
9	whole	7.5 a	1.64 a	37.05 a	9.8 a	0.05 b	6.47 a
	fresh-cut	3.0 b	1.51 ab	27.45 b	9.4 a	0.07 a	6.11 b
	fresh-cut (light)	3.0 b	1.38 b	26.87 b	9.5 a	0.07 a	6.01 c

[a] Means ($n = 3$) in each column followed by the same letter at each time do not differ significantly at P<0.05.

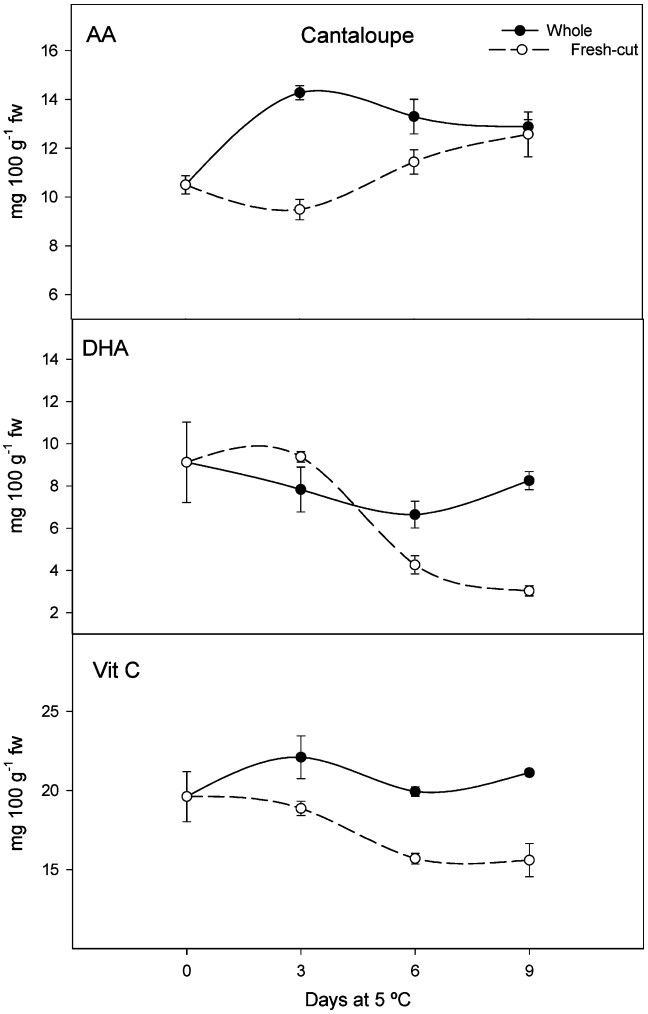

Figure 5. Ascorbic acid (AA), dehydroascorbic acid (DHA), and vitamin C (Vit C) of cantaloupe cubes from whole stored or fresh-cut fruit. Values are means of three replicates of 12 cubes each ± standard error.

14 °C is the recommended temperature for storing whole watermelons to avoid chilling injury (*25*). At day 9, fresh-cut watermelon cubes showed a better overall quality than whole watermelon stored at 5 °C. There were no differences in firmness over the 9-day storage period between fresh-cut and whole melon stored at either 5 or 14 °C. The selected parameter related to color changes for watermelon cubes was hue angle ($H°$). All cubes resulted in similar $H°$ color except cubes from the whole fruit stored at 5 °C, for which $H°$ tended to decrease. This could be explained by the dark red appearance of these tissues due to the development of slight "water-soaked" areas when the whole

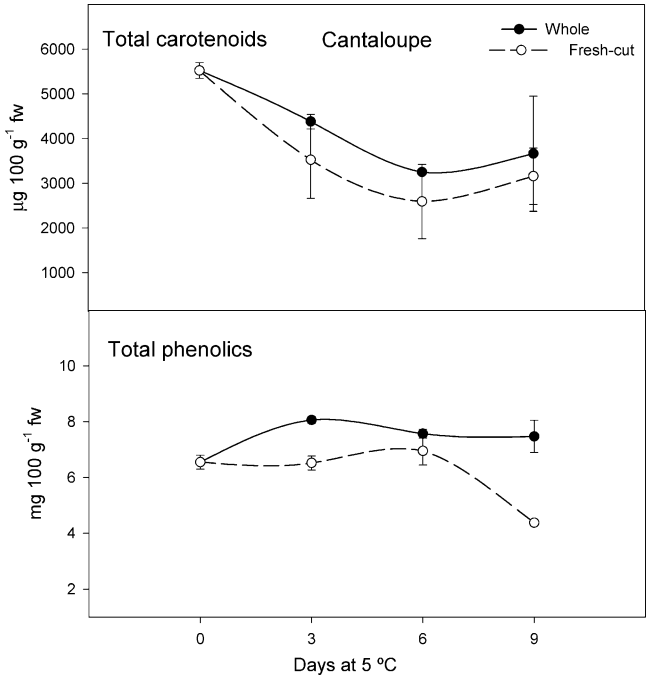

Figure 6. Total carotenoids and total phenolics content of cantaloupe cubes from whole stored or fresh-cut fruit. Values are means of three replicates of 12 cubes each ± standard error.

watermelon was stored at 5 °C but not at 14 °C. There were no differences in SSC and TA between fresh-cut watermelon and whole fruit either at 5 °C or at 14 °C (**Table 5**). The slight changes in quality indices observed with processing and storage of fresh-cut watermelon show the good quality of the used watermelon, which was processed after harvest without exposure to ethylene. Rushing et al. (*46*) described quality degradation of fresh-cut watermelon, including loss of texture, color, and sweetness. In our study, the excellent initial quality of the watermelon prevented juice leakage, which has been related to chilling injury (*47*).

In addition, there were no differences in the quality indices of watermelon cubes exposed to light and those kept in the dark except the pH value, which was higher for light-exposed cubes.

Changes in Vitamin C. AA was the only form of vitamin C detected in watermelon, and the content was low compared with other fruits. There were no significant differences in the content of AA between fresh-cut and whole fruit stored at 5 °C except at the end of the storage, when a slight decrease was observed for fresh-cut watermelon (**Figure 7**).

Changes in Carotenoids. Watermelon has been reported to be an excellent source of lycopene (*47*). The lycopene content in this cultivar (Tri-X313) was higher than that reported for

Table 5. Quality Indices of Whole and Fresh-Cut 'Tri-X 313' Watermelon Stored for up to 9 Days at 5 and 14 °C[a]

days	watermelon	visual quality (1–9)	firmness (N)	color ($H°$)	soluble solids (%)	titratable acidity (%)	pH
initial		8.8	1.39	32.66	9.4	0.11	5.10
3	whole	8.3 a	1.30 a	33.40 a	9.8 a	0.11 a	5.09 a
	fresh-cut	7.8 a	1.22 a	33.33 a	10.1 a	0.10 a	5.23 a
6	whole	8.0 a	1.29 a	34.53 a	9.8 a	0.11 a	5.00 a
	fresh-cut	7.4 b	1.32 a	34.07 a	10.1 a	0.11 a	5.14 a
9	whole, 5 °C	5.5 b	1.24 a	33.61 b	9.8 a	0.11 a	5.21 b
	whole, 14 °C	7.3 a	1.34 a	34.51 a	9.5 a	0.10 a	5.20 b
	fresh-cut	6.5 ab	1.37 a	33.92 ab	9.3 a	0.11 a	5.22 b
	fresh-cut (light)	7.3 a	1.23 a	34.44 ab	9.3 a	0.10 a	5.40 a

[a] Means ($n = 3$) in each column followed by the same letter at each time do not differ significantly at $P < 0.05$.

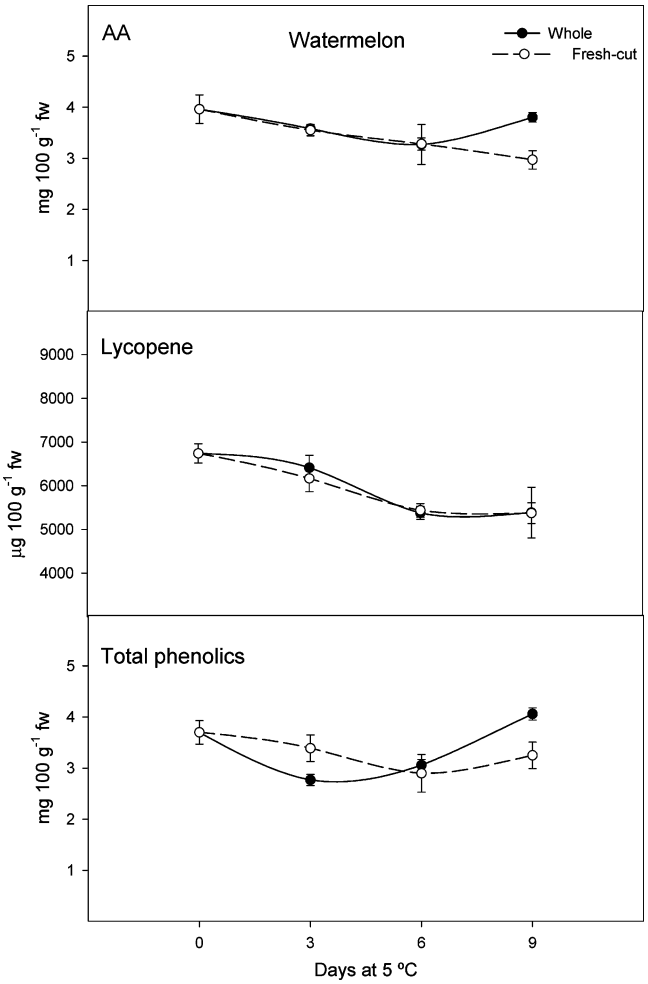

Figure 7. Ascorbic acid (AA), lycopene, and total phenolics content of watermelon cubes from whole stored or fresh-cut fruit. Values are means of three replicates of 10 cubes each ± standard error.

other watermelon cultivars, which can also vary by the production sources and seasons (*48*). In this cultivar, lycopene was found to be present as 75% of the total carotenoids content. Fresh-cut watermelon and whole fruit had the same lycopene content, and slight changes were observed over storage (**Figure 7**). Total carotenoids content did not change significantly in either kind of cube stored for 6 days, but was slightly reduced at day 9. These results agree with those observed by Perkins-Veazie and Collins (*47*), who found that fresh-cut watermelon held for ≥7 days at 2 °C had an insignificant loss of lycopene.

Changes in Phenolics. Watermelon contained small amounts of phenolics (<4 mg 100 g^{-1} of FW) that were mainly hydroxycinnamic acid derivatives. They were quantified as *p*-coumaric acid. No degradation was observed during 9 days of storage in either whole or fresh-cut fruit (**Figure 7**).

No effect of light exposure for 9 days of storage on the nutritional content was observed because no differences in the content of vitamin C, total carotenoids, and total phenolics were found between watermelon cubes exposed to light or dark conditions (**Table 2**).

Strawberry. *Changes in Quality Indices*. The visual quality of the strawberry slices decreased over storage and was significantly different from the whole strawberry slices after 3 days of storage (**Table 6**). After 6 days at 5 °C, fresh-cut slices were scored under the limit of marketability in accordance with Aguayo et al. (*49*), who found a shelf life shorter than 9 days at 5 °C in strawberry slices. Firmness decreased by 40% after storage of fresh-cut strawberry relative to the initial and was significantly different from the whole strawberry slices at the end of the storage. Fresh-cut strawberries had lower $H°$ than slices from the whole stored fruit over storage, indicating a surface darkening as described in previous papers (*18*). There were only small differences in SSC, TA, and pH between fresh-cut slices and those slices from the whole stored strawberries. No effect of light exposure during storage was observed because no significant differences in quality indices were shown between strawberry slices exposed to light or dark conditions after 9 days of storage, except for SSC (**Table 6**).

Changes in Vitamin C. The content of AA in strawberry slices of both fresh-cut and whole fruit slightly increased during storage (**Figure 8**). However, by day 9, the content of AA decreased in fresh-cut slices, whereas DHA increased, to result in a increase in the content of vitamin C. This fact could be explained by the reversible oxidation of AA to DHA maintaining the vitamin C content and also shows that when vitamin C levels are reported, DHA has to be taken into consideration (*11*). Whole fruit slightly increased in AA, DHA, and vitamin C content over storage. Fresh-cut strawberries held for 7 days at 5 °C were shown to have the same level of vitamin C as whole fresh strawberries (*18*), in agreement with our results.

Changes in Carotenoids. The total carotenoids content in 'Seascape' strawberries was ≈90 μg 100 g^{-1} of FW, which is similar to that reported for 'Tenira' cultivar (*45*). There was no significant change in the total carotenoids content of fresh-cut slices and sliced strawberry fruit over the time of storage with the exception of day 9, when lower and higher contents of total carotenoids were found for fresh-cut slices and sliced fruit, respectively (**Figure 9**). Therefore, no significant loss of total carotenoids occurred before slices reached their limit of marketability due to loss of quality.

Table 6. Quality Indices of Whole and Fresh-Cut 'Seascape' Strawberry Stored for up to 9 Days at 5[a]

days	strawberry	visual quality (1–9)	firmness (N)	color ($H°$)	soluble solids (%)	titratable acidity (%)	pH
initial		7.8	1.14	44.91	7.2	0.93	3.27
3	whole	6.8 a	0.98 a	43.04 a	6.8 a	0.75 a	3.36 a
	fresh-cut	5.8 a	0.99 a	41.16 b	6.9 a	0.77 a	3.36 a
6	whole	7.5 a	1.02 a	43.94 a	6.9 a	0.78 a	3.34 a
	fresh-cut	5.5 b	0.95 a	41.97 b	6.8 a	0.73 a	3.35 a
9	whole	5.5 a	1.05 a	44.19 a	6.7 a	0.79 a	3.33 b
	fresh-cut	3.5 b	0.69 b	41.91 ab	6.7 a	0.70 b	3.40 a
	fresh-cut (light)	3.5 b	0.69 b	40.65 b	6.4 b	0.71 b	3.40 a

[a] Means ($n = 3$) in each column followed by the same letter at each time do not differ significantly at $P < 0.05$.

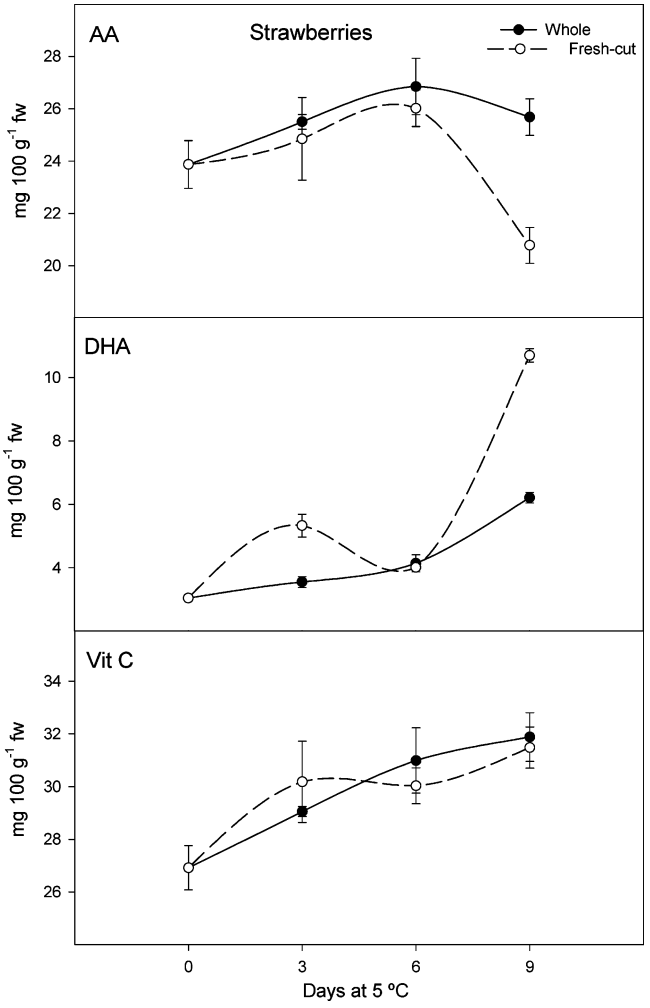

Figure 8. Ascorbic acid (AA), dehydroascorbic acid (DHA), and vitamin C (Vit C) of strawberry slices from whole stored or fresh-cut fruit. Values are means of three replicates of 150 g each ± standard error.

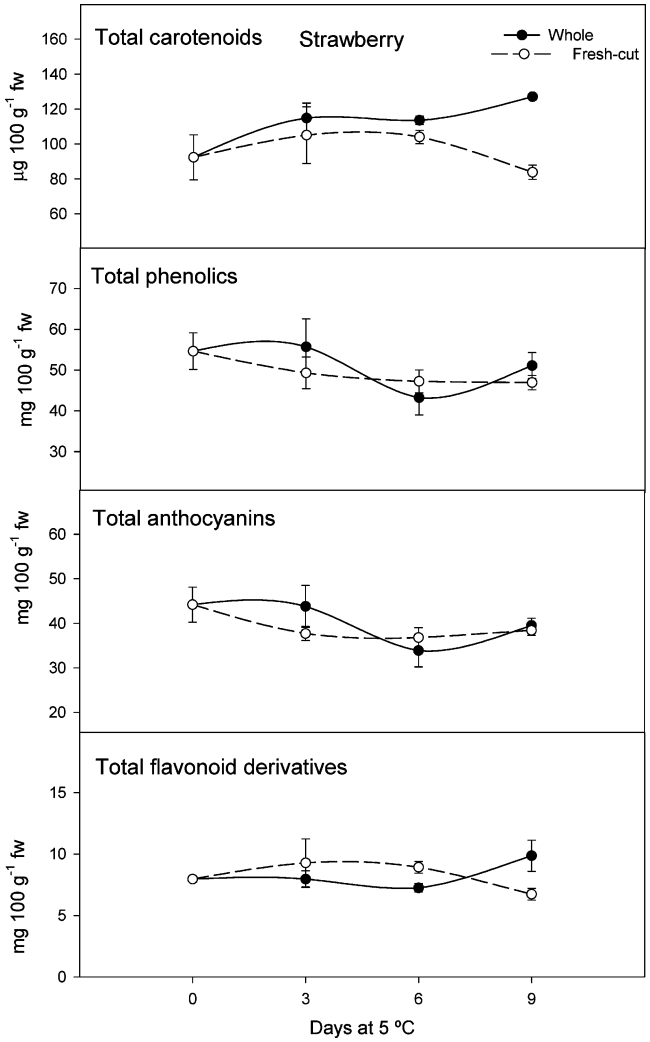

Figure 9. Total carotenoids, total phenolics, total anthocyanins, and total flavonoid derivatives of strawberry slices from whole stored or fresh-cut fruit. Values are means of three replicates of 150 g each ± standard error.

Changes in Phenolics. This fruit was the richest in phenolic compounds, reaching values close to 60 mg 100 g^{-1} of FW. The main phenolics detected in strawberry were anthocyanins (pelargonidin 3-glucoside), flavonols (quercetin 3-glucuronide + 3-glucoside and traces of kaempferol derivatives), hydroxycinnamates (mainly *p*-coumaroylglucose), and ellagic acid derivatives. Anthocyanins were quantified as pelargonidin, flavonols as rutin, hydroxycinnamates as *p*-coumaric acid, and ellagic acid derivatives as ellagic acid (*29*). The content of total phenolic compounds was well preserved during 9 days of storage at 5 °C, and no significant differences were found between fresh-cut slices and sliced fruit (**Figure 9**). Total anthocyanins and total flavonoids derivatives did not change significantly in either sliced strawberry over storage.

No effect of light exposure for 9 days of storage on the nutritional content was observed because no differences in the content of vitamin C, total carotenoids, and total phenolics were found between strawberry slices exposed to light and dark conditions (**Table 2**).

Kiwifruit. *Changes in Quality Indices.* The visual quality of fresh-cut kiwifruit decreased rapidly over storage (**Table 7**). After 6 days at 5 °C, fresh-cut kiwifruit were scored under the

Table 7. Quality Indices of Whole and Fresh-Cut 'Hayward' Kiwifruit Stored for up to 9 Days at 5 °C[a]

days	kiwifruit	visual quality (1–9)	firmness (N)	color (*L**)	oluble solids (%)	titratable acidity (%)	pH
initial		9.0	0.95	39.97	11.1	0.92	3.50
3	whole	8.3 a	0.90 a	47.17 a	11.6 a	0.98 a	3.49 a
	fresh-cut	5.0 b	0.52 b	34.88 b	11.2 a	0.96 a	3.52 a
6	whole	6.8 a	0.76 a	47.37 a	10.9 a	0.97 a	3.48 a
	fresh-cut	4.0 b	0.41 b	35.06 b	11.1 a	0.91 a	3.56 a
9	whole	6.5 a	0.61 a	46.88 a	11.9 a	1.02 a	3.50 a
	fresh-cut	2.5 b	0.42 b	34.57 b	11.5 b	0.92 b	3.51 a
	fresh-cut (light)	2.5 b	0.44 b	33.87 b	11.1 c	0.94 b	3.52 a

[a] Means ($n = 3$) in each column followed by the same letter at each time do not differ significantly at $P < 0.05$.

limit of marketability, indicating a shelf life shorter than 6 days, and reached the limit of usability by day 9. It has been pointed out that the most obvious change in kiwifruit slices was a rapid loss in firmness, which is noticeable a few hours after processing, even at 2 °C (*50*). The firmness of kiwifruit slices decreased rapidly during the first 3 days of storage as has already been observed (*23*, *50*). Fresh-cut kiwifruit has been described to break down rapidly because of its high water content and soft texture in addition to microbial growth (*51*). After storage, the texture loss of sliced whole kiwifruit was 32% lower with respect to the initial. The color *L** value of kiwifruit slices (surface darkening) was lower for kiwifruit slices than for slices of whole fruits. The cut surface darkening was due to induction of a translucent water-soaked tissue and not to enzymatic browning (*23*). A slight decrease in SSC and TA of fresh-cut fruit compared to slices of whole stored fruit was observed at the end of storage. There was no difference in pH between slices. Light exposure did not influence the quality indices of those slices exposed to light and had only a slight effect on SSC (**Table 7**).

Changes in Vitamin C. The vitamin C content in kiwifruit cultivars has been shown to vary from 29 to 80 mg 100 g^{-1} of FW (*52*). In our study, the Hayward cultivar contained 43 mg 100 g^{-1} of FW of vitamin C including 3 mg 100 g^{-1} of FW of DHA, whereas in other studies a higher vitamin C content has been reported (65 mg 100 g^{-1} of FW) (*23*, *52*). Fresh-cut slices stored at 5 °C exhibited a gradual decrease in AA and an increase in DHA (**Figure 10**). The vitamin C content was 7.5% lower than initial values in fresh-cut slices after 9 days of storage, whereas there were no changes for slices of whole stored fruit. In agreement with Agar et al. (*23*), kiwifruit slices held for 9 days at 5 °C had no significant loss in vitamin C.

Changes in Carotenoids. A higher content of carotenoids has been reported for kiwifruit in which lutein accounts for 45% of the total carotenoids, followed by *trans*-neoxanthin and β-carotene (*45*). The average lutein and β-carotene content in these kiwifruits represented 34 and 10%, respectively, of the total content and did not change significantly in slices from either fresh-cut or whole stored fruit over the storage period (**Figure 11**).

Changes in Phenolics. Kiwifruit contained small amounts of phenolics ($\approx$4 mg 100 g^{-1} of FW) that were of benzoic and hydroxycinnamic (chlorogenic and *p*-coumaric acid derivative) type in accordance with previous results (*53*). They were quantified as *p*-coumaric acid or gallic acid depending on their UV spectrum. During 9 days of storage no significant changes were observed in the phenolic content, and no effect of processing was observed because no difference was found between slices from the whole fruit and fresh-cut slices (**Figure 11**).

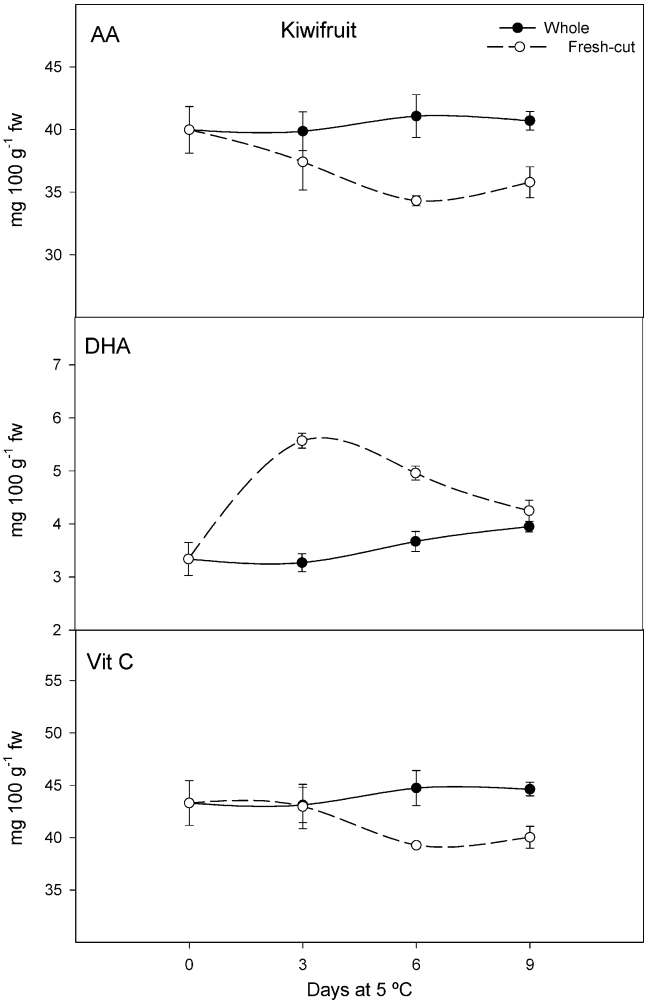

Figure 10. Ascorbic acid (AA), dehydroascorbic acid (DHA), and vitamin C (Vit C) of kiwifruit slices from whole stored or fresh-cut fruit. Values are means of three replicates of 12 slices each ± standard error.

In the presence of light, vitamin C and total carotenoids contents of kiwifruit slices decreased, whereas total phenolics content was maintained after 9 days of storage (**Table 2**). However, fresh-cut kiwifruit visually spoiled before any significant nutrient loss occurred.

General Overview. Among the many sensory characteristics of fresh-cut fruits, appearance, texture, and flavor are of prime importance (*12*). In addition to these general sensory characteristics, consumers are nowadays more and more concerned with the nutritional qualities of what they eat. Nutritional value varies greatly among commodities and cultivars of each commodity. Processors of fresh-cut fruit products must know

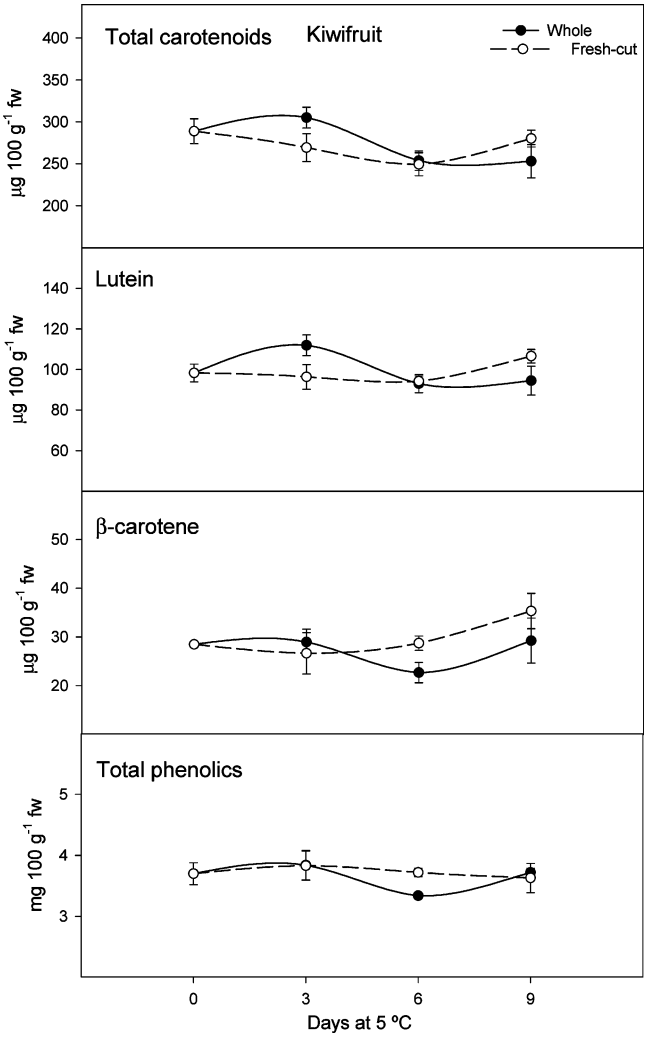

Figure 11. Total carotenoids, lutein, β-carotene, and total phenolics content of kiwifruit slices from whole stored or fresh-cut fruit. Values are means of three replicates of 12 slices each ± standard error.

which cultivars of fruits are best for processing and choose by taking into account not only the appearance but also the nutritional content. The effect of preparation steps involved in fresh-cut fruit production has been described to decrease the nutritional content (*15*, *54*). The aim of this work was to determine the influence of processing and storage on the postcutting life and nutritional quality of fresh-cut fruits. The concentration of antioxidant constituents was quite well preserved during the processing and storage of the studied fresh-cut fruits. Storage of whole fruits at 5 °C led to nutritional changes similar to those found for the fresh-cut fruits, although the postcutting life was shorter than 6 days for fresh-cut kiwifruit and shorter than 9 days for fresh-cut pineapple, cantaloupe, and strawberry but extended over 9 days for fresh-cut watermelon and mango. The benefits of firmness retention and/or antioxidant dips and modified atmosphere packaging (MAP) could help to extend fruit shelf life (*23*, *32*, *33*, *55*−*57*).

The results show the importance of determining vitamin C content by the summation of AA and DHA; otherwise, the content of vitamin C in fresh-cut pineapple, mango, cantaloupe, strawberry, and kiwifruit could be underestimated. Wright and Kader (*18*) found a lower DHA content in strawberries (pH 3.4−3.7) and a higher DHA content in persimmons (pH 5.4−6.0). This fact was also confirmed with this study as well as the tendency for near-neutral pH fruit, as is the case of fresh-cut cantaloupe, to lose DHA during storage, whereas it was well preserved in the other fruits that have acid pH. The preservation of fruit phenolic content has a great impact on the quality of fresh-cut fruits because of the contribution of phenols not only in enzymatic browning reactions but also on the nutritional value of fresh-cut products. Protection from light (e.g., opaque materials) has been described to be a physical procedure that ensures retention of antioxidant in fruits (*58*). From our results, transparent containers have no detrimental effect on nutritional quality.

Contrary to expectations, it was clear that minimal processing had almost no effect on the main antioxidant constituents. The changes in nutrient antioxidants observed during 9 days at 5 °C would not significantly affect the nutrient quality of fresh-cut fruits. Light exposure during storage had no effect on decreasing quality and nutrient content. However, as minimal processing accelerates the end of the postcutting life due to a reduction in visual quality, further studies are needed to evaluate the effect of postcutting treatments, including MAP and chemical dips for delaying softening and browning, on the nutrient retention of fresh-cut fruits.

ACKNOWLEDGMENT

We thank Dr. Marita Cantwell for supplying melon samples and Dr. Francisco A. Tomás-Barberán for phenolic characterization.

LITERATURE CITED

(1) Block, G.; Patterson, B.; Subar, A. Fruits and vegetables, and cancer prevention: a review of the epidemiological evidence. *Nutr. Cancer* **1992**, *18*, 1−29.

(2) Liu, S.; Manson, J. E.; Lee, I.-M.; Cole, S. R.; Hennekens, C. H.; Willet, W. C.; Buring, J. E. Fruit and vegetable intake and risk of cardiovascular disease: the Women's Health Study. *Am. J. Clin. Nutr.* **2000**, *72*, 922−928.

(3) Martin, A.; Cherubini, A.; Andres-Lacueva, C.; Paniagua, M.; Joseph, J. A. Effects of fruits and vegetables on levels of vitamins E and C in the brain and their association with cognitive performance. *J. Nutr. Health Aging* **2002**, *6*, 392−404.

(4) Doll, R. An overview of the epidemiological evidence linking diet and cancer. *Proc. Nutr. Soc.* **1990**, *49*, 119−131.

(5) Rimm, E. B.; Katan, M. B.; Ascherio, A.; Stampfer, M. J.; Willett, W. C. Relation between intake of flavonoids and risk of coronary heart disease in male health professionals. *Ann. Intern. Med.* **1996**, *125*, 384−389.

(6) Tee, E.-S. Carotenoids and retinoids in human nutrition. *Crit. Rev. Food Sci. Nutr.* **1992**, *31*, 103−163.

(7) Grassmann, J.; Hippeli, S.; Elstre, E. F. Plant's defense mechanism and its benefits for animals and medicine: role of phenolics and terpenoids in avoiding oxygen stress. *Plant Physiol. Biochem.* **2002**, *40*, 471−478.

(8) Gaziano, J. M.; Hennekens, C. H. The role of β-carotene in the prevention of cardiovascular disease. In *Carotenoids in Human Health*; Canfield, L. M., Krinsky, N. I., Olson, J. A., Eds.; New York Academia of Science: New York, 1993; pp 148−155.

(9) Watada, A. E. Vitamins. In *Postharvest Physiology of Vegetables*; Weichmann, J., Ed.; Dekker: New York, 1987; pp 455−468.

(10) Nunes, M. C. N.; Brecht, J. K.; Morais, A. M. M. B.; Sargent, S. A. Controlling temperature and water loss to maintain ascorbic acid levels in strawberries during postharvest handling. *J. Food Sci.* **1998**, *63*, 1033−1036.

(11) Lee, S. K.; Kader, A. A. Preharvest and postharvest factors influencing vitamin C content of horticultural crops. *Postharvest. Biol. Technol.* **2000**, *20*, 207−220.

(12) Kader, A. A. Quality parameters of fresh-cut fruit and vegetables products. In *Fresh-cut Fruits and Vegetables*; Lamikanra, O., Ed.; Science, Technology and Market; CRC Press: Boca Raton, FL, 2002; pp 11−20.
(13) Hussein, A.; Odumeru, J. A.; Ayanbadejo, T.; Faulkner, H.; McNab, W. B.; Hager, H.; Szijarto, L. Effects of processing and packaging on vitamin C and β-carotene content of ready-to-use (RTU) vegetables. *Food Res. Int*. **2000**, *33*, 131−136.
(14) Soliva-Fortuny, R. C.; Martín- Belloso, O. New advances in extending the shelf-life of fresh-cut fruits: a review. *Trends Food Sci. Technol*. **2003**, *14*, 341−353.
(15) Klein, B. P. Nutritional consequences of minimal processing of fruits and vegetables. *J. Food Qual*. **1987**, *10*, 179−193.
(16) Huxsoll, C. C.; Bolin, H. R.; King, A. D. Physiochemical changes and treatments for lightly processed fruits and vegetables. In *Quality Factors of Fruits and Vegetables*; Jen, J. J., Ed.; Chemistry and Technology; ACS Symposium Series 405; American Chemical Society: Washington, DC, 1989; pp 203−215.
(17) Bode, A. M.; Cunningham, L.; Rose, R. C. Spontaneous decay of oxidized ascorbic acid (dehydro-L-ascorbic acid) evaluated by high-pressure liquid chromatography. *Clin. Chem*. **1990**, *36*, 1807−1809.
(18) Wright, K. P.; Kader, A. A. Effect of slicing and controlled-atmosphere storage on the ascorbate content and quality of strawberries and persimmons. *Postharvest. Biol. Technol*. **1997**, *10*, 39−48.
(19) Vámos-Vigyázó, L. Polyphenol oxidase and peroxidase in fruits and vegetables. *CRC Crit. Rev. Food Sci. Nutr*. **1981**, *15*, 49−127.
(20) Watada, A. E.; Abe, K.; Yamauchi, N. Physiological activities of partially processed fruits and vegetables. *Food Technol*. **1990**, *44*, 116, 118, 120−122.
(21) Thompson, J. E.; Legge, R. L.; Barber, R. F. The role of free radicals in senescence and wounding. *New Phytol*. **1987**, *105*, 317−344.
(22) Wright, K. P.; Kader, A. A. Effect of controlled-atmosphere storage on the quality and carotenoid content of sliced persimmons and peaches. *Postharvest Biol. Technol*. **1997**, *10*, 89−97.
(23) Agar, I. T.; Massantini, R.; Hess-Pierce, B.; Kader, A. A. Postharvest CO_2 and ethylene production and quality maintenance of fresh-cut kiwifruit slices. *J. Food Sci*. **1999**, *64*, 433−440.
(24) Chantanawarangoon, S.; Kader, A. A. Calcium treatments and modified atmospheres extended post-cutting life of mango cubes. Presented at the Institute of Food Technologists' Annual Meeting and Food Expo, Anaheim, CA, 2002.
(25) Suslow, T. V. Produce facts: watermelon; University of California, Davis, Postharvest Website, http://postharvest.ucdavis.edu/Produce/ProduceFacts/Fruit/watermelon.shtml.
(26) McGuire, R. G. Reporting of objective color measurements. *HortScience* **1992**, *27*, 1254−1255.
(27) Minolta. *Precise Color Communication*; Minolta Co.: Tokyo, Japan, 1994.
(28) Tomás-Barberán, F. A.; Gil, M. I.; Cremin, P.; Waterhouse, A. L.; Hess-Pierce, B.; Kader, A. A. HPLC-DAD-ESIMS analysis of phenolic compounds in nectarines, peaches, and plums. *J. Agric. Food Chem.* **2001**, *49*, 4748−4760.
(29) Gil, M. I.; Holcroft, D. M.; Kader, A. A. Changes in strawberry anthocyanins and other polyphenols in response to carbon dioxide treatments. *J. Agric. Food Chem.* **1997**, *45*, 1662−1667.
(30) Zapata, S.; Dufour, J. P. Ascorbic, dehydroascorbic and isoascorbic acid simultaneous determinations by reverse phase ion interaction HPLC. *J. Food Sci*. **1992**, *57*, 506−511.
(31) Hart, D. J.; Scott, K. J. Development and evaluation of an HPLC method for the analysis of carotenods in foods, and the measurement of the carotenoid content of vegetables and fruits commonly consumed in the UK. *Food Chem*. **1995**, *54*, 101−111.
(32) Marrero, A.; Kader, A. A. Factors affecting the post-cutting life and quality of minimally processed pineapple. *Acta Hortic*. **2001**, *553*, 705−706.
(33) González-Aguilar, G. A.; Ruiz-Cruz, S.; Cruz-Valenzuela, R.; Rodríguez-Félix, A.; Wang, C. Y. Physiological and quality changes of fresh-cut pineapple treated with antibrowning agents. *Lebensm.-Wiss. -Technol*. **2004**, *37*, 369−376.
(34) Rocha, A. M. C. N.; Brochado, C. M.; Kirby, R.; Morais, M. M. B. Shelf-life of chilled cut orange determined by sensory quality. *Food Control* **1995**, *6*, 317−322.
(35) Sawamura, M.; Ooishi, S.; Zhong-Fu, L. Reduction of dehydroascorbic acid by sodium hydrosulphide and liquid chromatographic determination of vitamin C in citrus juice. *J. Sci. Food Agric*. **1990**, *53*, 275−278.
(36) Brat, P.; Nguyen Thi Hoang, L.; Soler, A.; Reynes, M.; Brillouet, J. M. Physicochemical characterization of a new pineapple hybrid (FLHORAN41 Cv.). *J. Agric. Food Chem.* **2005**, *52*, 6170−6177.
(37) Wen, L.; Wrostad, R. E. Phenolic composition of authentic pineapple juice. *J. Food Sci.* **1999**, *67*, 155−161.
(38) Rattanapanone, N.; Lee, Y.; Wu, T.; Watada, A. E. Quality and microbial changes of fresh-cut mango cubes held in controlled atmospheres. *HortScience* **2001**, *36*, 1091−1095.
(39) USDA. *Nutrient Database for Standard References*, release 13; Food Group 09, Fruits and Fruit Juices; 1999; available at http://www.nal.usda.gov/fnic/cgi-bin/list_nut.pl.
(40) Litz, R. E. In *The Mango: Botany, Production, and Uses*; CAB International: Wallingford, U.K., 1997.
(41) Macheix, J. J.; Fleuriet, A.; Billot, J. In *Fruit Phenolics*; CRC Press: Boca Raton, FL, 1990; p 109.
(42) Portela, S. I.; Cantwell, M. I. Cutting blade sharpness affects appearance and other quality attributes of fresh-cut cantaloupe melon. *J. Food Sci*. **2001**, *66*, 1265−1270.
(43) Aguayo, E.; Escalona, V. H.; Artés, F. Metabolic behaviour and quality changes of whole and fresh processed melon. *J. Food Sci*. **2004**, *69*, 148−155.
(44) Lamikanra, O.; Watson, M. A. Cantaloupe melon, peroxidase: characterization and effects of food additives on activity. *Nahrung* **2000**, *44*, 168−172.
(45) Gross, J. In *Pigments in Fruits*; Academic Press: London, U.K., 1987; pp 220−258.
(46) Rushing, J. W.; Fonseca, J. M.; Keinath, A. P. Harvesting and postharvest handling. In *Watermelons: Characteristics, Production, and Marketing*; Maynard, D., Ed.; American Society for Horticultural Science Press: Alexandria, VA, 2001.
(47) Perkins-Veazie, P.; Collins, J. K. Flesh quality and lycopene stability of fresh-cut watermelon. *Postharvest Biol. Technol*. **2004**, *31*, 159−166.
(48) Perkins-Veazie, P.; Collins, J. K.; Pair, S. D.; Roberts, W. Lycopene content of differs among red-fleshed watermelon cultivars. *J. Sci. Food Agric*. **2001**, *81*, 1−5.
(49) Aguayo, E.; Jansasithorn, R.; Kader, A. A. Combined effects of 1-methylcyclopropene, calcium chloride dip, and/or atmospheric modification on quality changes in fresh-cut strawberries. *Postharvest Biol. Technol*. **2006**, in press.
(50) Varoquaux, P.; Lecendre, I.; Varoquaux, F.; Souty, M. Change in firmness of kiwifruit after slicing. *Sci. Aliments* **1990**, *10*, 127−139.
(51) Wang, C. Y.; Buta, J. G. Maintaining quality of fresh-cut kiwifruit with volatile compounds. *Postharvest Biol. Technol*. **2003**, *28*, 181−186.
(52) Nishiyama, I.; Yamashita, Y.; Yamanaka, M.; Shimohashi, A.; Fukuda, T.; Oota, T. Varietal differences in vitamin C content in the fruit of kiwifruit and other *Actinia* species. *J. Agric Food Chem.* **2004**, *52*, 5472−5475.
(53) Dawes, H. M.; Keene, J. B. Phenolic composition of kiwifruit juice. *J. Agric. Food Chem.* **1999**, *47*, 2398−2403.
(54) McCarthy, M. A.; Matthews, R. H. Nutritional quality of fruits and vegetables subject to minimal processes. In *Minimally Processed Refrigerated Fruits and Vegetables*; Wiley, R. C., Ed.; Chapman and Hall: New York, 1994; pp 313−326.

(55) Luna-Guzmán, I.; Cantwell, M.; Barret, D. M. Fresh-cut cantaloupe: effects of $CaCl_2$ dips and heat treatments on firmness and metabolic activity. *Postharvest Biol. Technol.* **1999**, *17*, 201−213.

(56) Gorny, J. R.; Hess-Pierce, B.; Kader, A. A. Quality changes in fresh-cut peach and nectarine slices as affected by cultivar, storage atmosphere and chemical treatments. *J. Food Sci.* **1999**, *64*, 429−432.

(57) Gorny, J. R.; Hess-Pierce, B.; Cifuentes, R. A.; Kader, A. A. Quality changes in fresh-cut pear slices as affected by controlled atmospheres and chemical preservatives. *Postharvest Biol. Technol*. **2002**, *24*, 271−278.

(58) Van den Berg, H.; Faulks, R.; Fernando Granado, H.; Hirschberg, J.; Olmedilla, B.; Sandmann, G.; Southon, S.; Stahl, W. The potential for the improvement of carotenoid levels in foods and the likely systemic effects. *J. Sci. Food Agric*. **2000**, *80*, 880−912.

Received for review February 1, 2006. Revised manuscript received April 10, 2006. Accepted April 11, 2006. M.I.G. thanks the Ministerio de Educación y Ciencia "Programa Salvador de Madariaga" and E.A. the Technical University of Cartagena for financial support.

JF060303Y